Feasibility of 100 year Reanalysis using only Surface Pressure Data

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Motivation

1. Would like to determine storminess and blocking variations over last 100 years. Currently available analyses are error-ridden hand-drawn SLP maps that do not make use all observations.
2. We should be able to do better with modern data assimilation systems.
3. Reanalyses with a fixed assimilation system are valuable for climate studies but varying observation networks introduce spurious climate variability.
4. Prior to 1948, few radiosondes are available, but newly recovered surface pressure observations raise the possibility of generating useful reanalyses of the lower tropospheric circulation.

Previous work

Whitaker et al. (2003, 2004) showed surface pressure observations will produce "good" 6-hourly analyses of Northern Hemisphere 500 mb heights using ensemble kalman filter.

Anderson (2003) used primitive equation model and ensemble filter with similar results.

Thepaut and Simmons (2003) used operational ECMWF 4D-Var with similar results.

Bengtsson et al. (2004) and Kanamitsu and Hwang (2005) concluded that surface observations are unable to produce reliable fields aloft using ERA-40 and NCEP-DOE 3D-Var systems.
Note that the first guess error statistics were assumed to be the same as in the modern era.

Experiment

1. In every 5°×5° degree box, use only surface pressure observations for 2001 to 2002 at densities typical of 1895, 1905, 1915, and 1935.

   - Ø No aircraft, balloon, satellite, or radiosonde data.
   - Ø ***1000 times fewer*** surface observations every 6 hours than currently used.

2. With these reduced observational densities, make 6-hourly assimilations for 2001-2002 using:

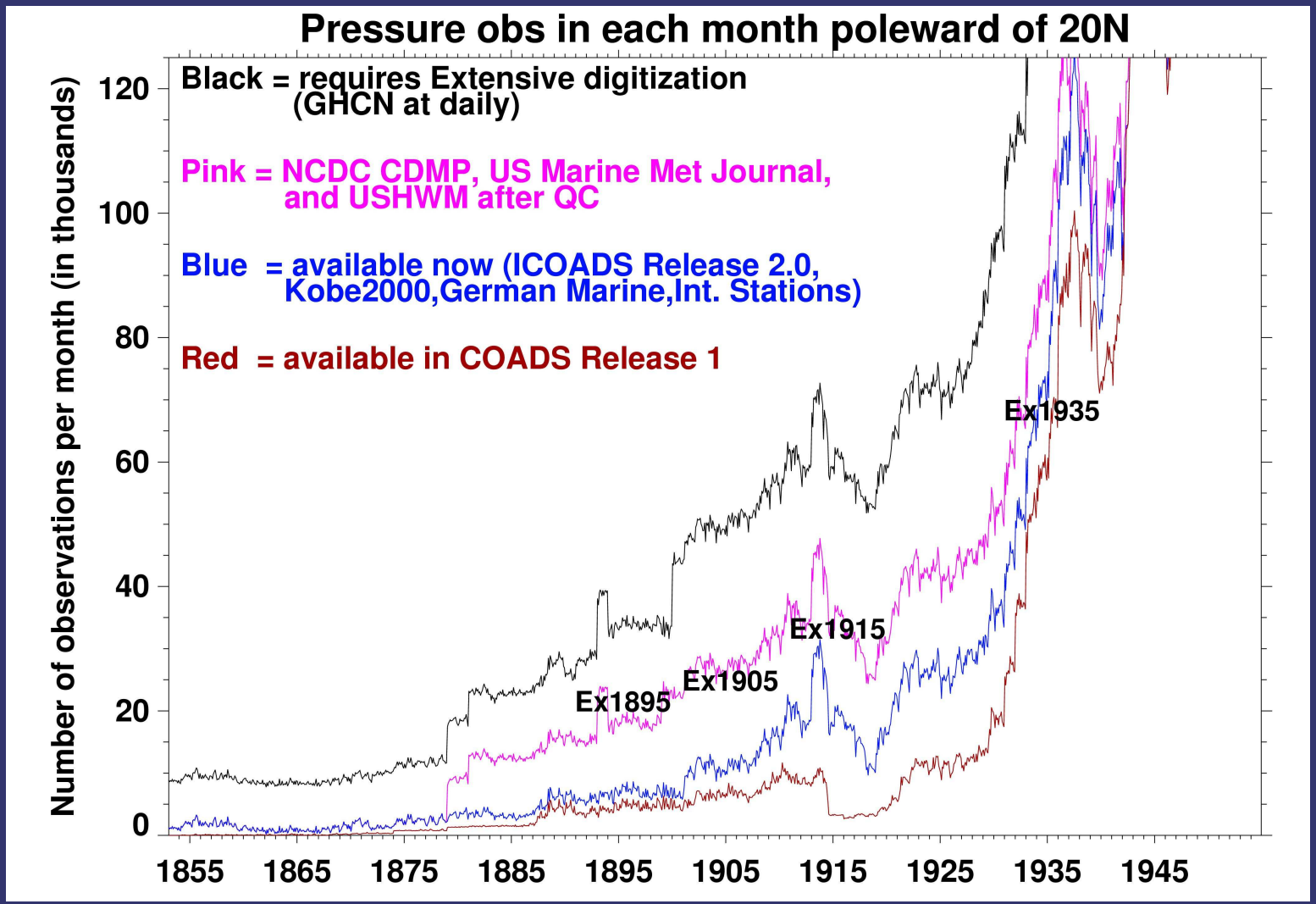
   a) Optimal Interpolation (OI) with climatological mean as the first guess and anomaly covariances as the error statistics of that first guess.

   b) The NCEP-NCAR CDAS with ***fixed*** "first-guess" error statistics derived from the NCEP medium range forecast model (MRF) tuned for surface pressure only.

   c) An Ensemble square root filter (EnSRF) with the mean of a 100 member ensemble from MRF as the first-guess and the ***time-varying*** ensemble covariance as the error in that first-guess (Whitaker and Hamill, 2002).

3. Compute error relative to the Full NCEP-NCAR reanalysis CDAS (Kalnay et al. 1996) and compare to 1979-2001 MRF re-forecasts (Hamill et al. 2004).

Number of historical surface pressure obs in each month (1855-1954) poleward of 20N



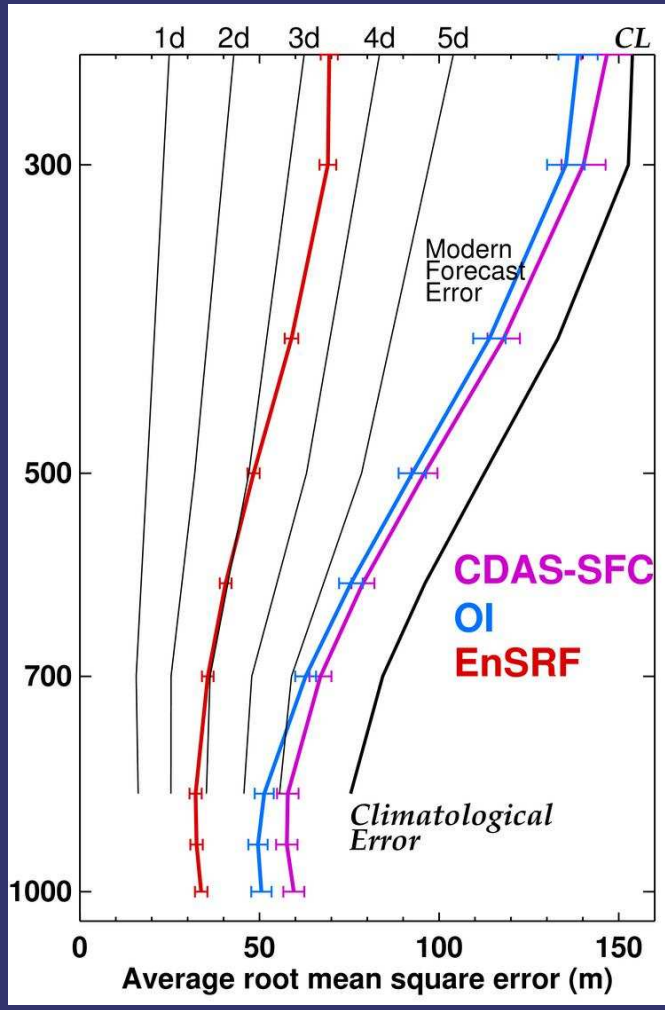
RMS Error and Anomaly Correlation Skill of 6-hourly geopotential height analyses using CDAS-SFC, Optimal Interpolation, and Ensemble Filter and Surface Pressure Obs at 1895 densities

Surface pressure obs alone produce a good 6-hourly analysis even at 1895 densities.

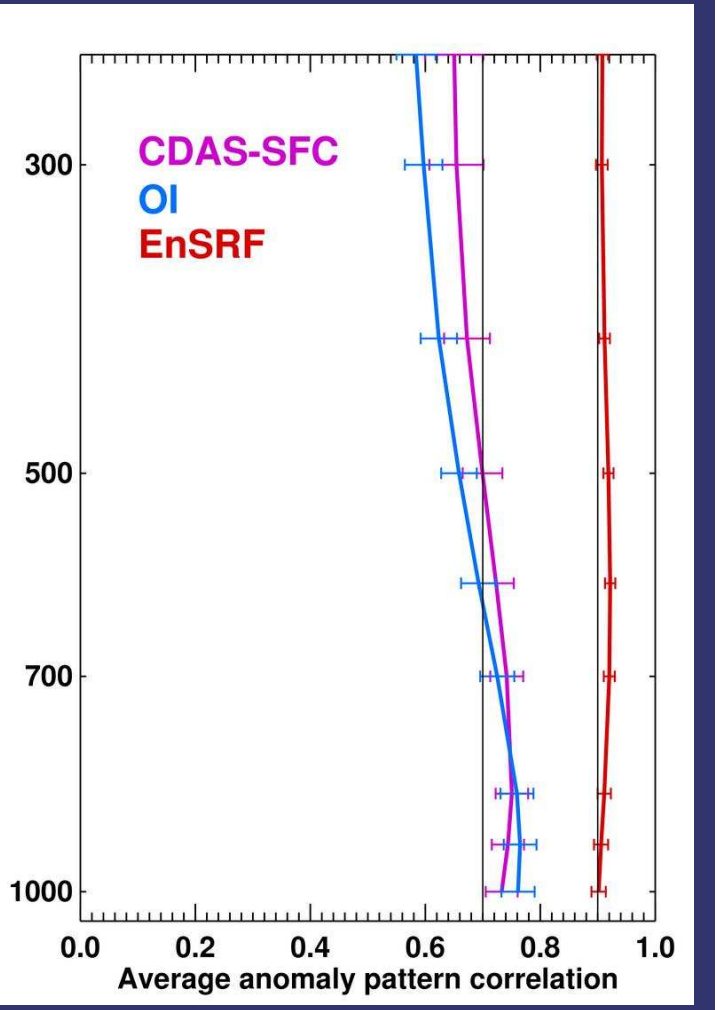
Results obtained using EnSRF are significantly better than the traditional CDAS.

Expected error for 1895 circulation is comparable to a 3-day forecast error.

RMS



anomaly correlation



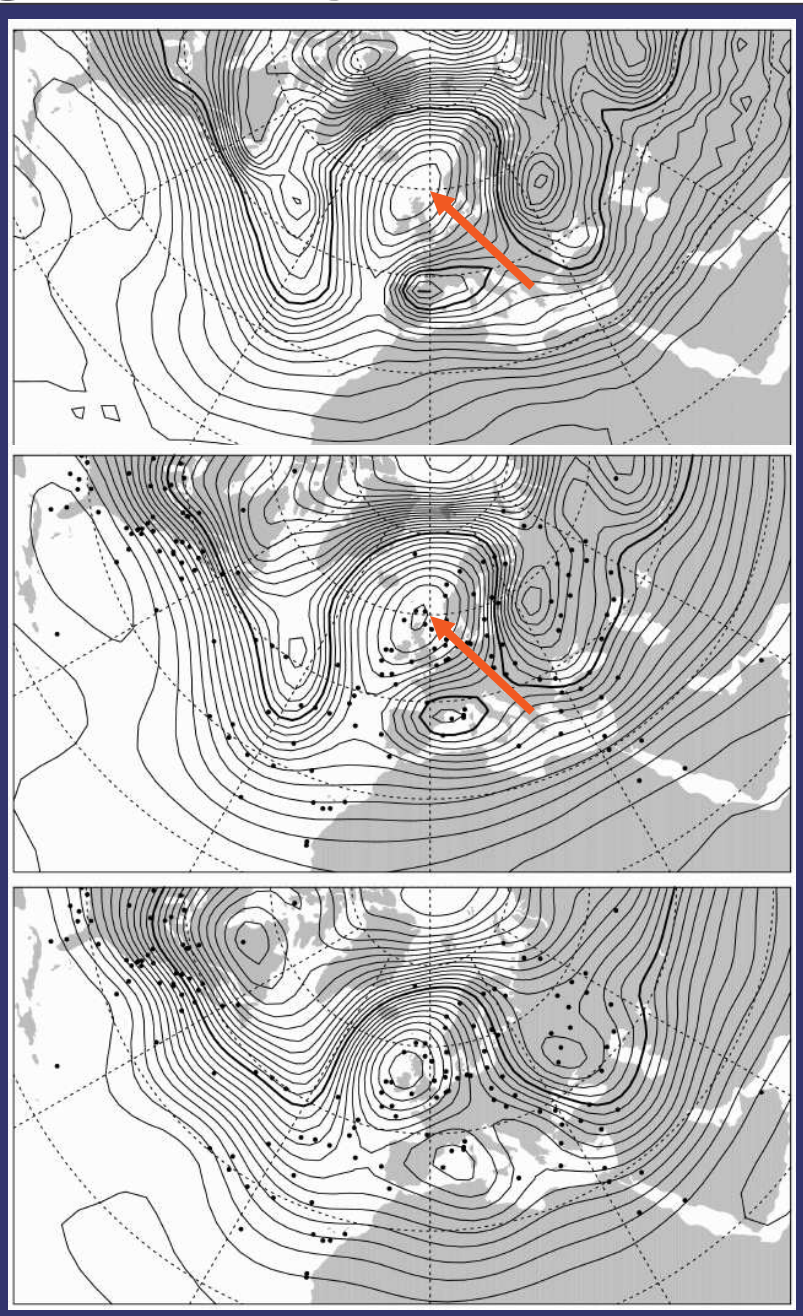
Simulating December 2001

500mb Height Analyses for 0Z 15 Dec 2001

Full CDAS
(120,000+ obs)

EnSRF 1895
(214 surface pressure obs)

Optimal Interpolation 1895
(214 surface pressure obs)



5500 m contour is thickened

Black dots show pressure ob locations

RMS = 39.8 m

RMS = 82.4 m

Comparison of ICOADS and US Historical Weather Map Feb 1 1899

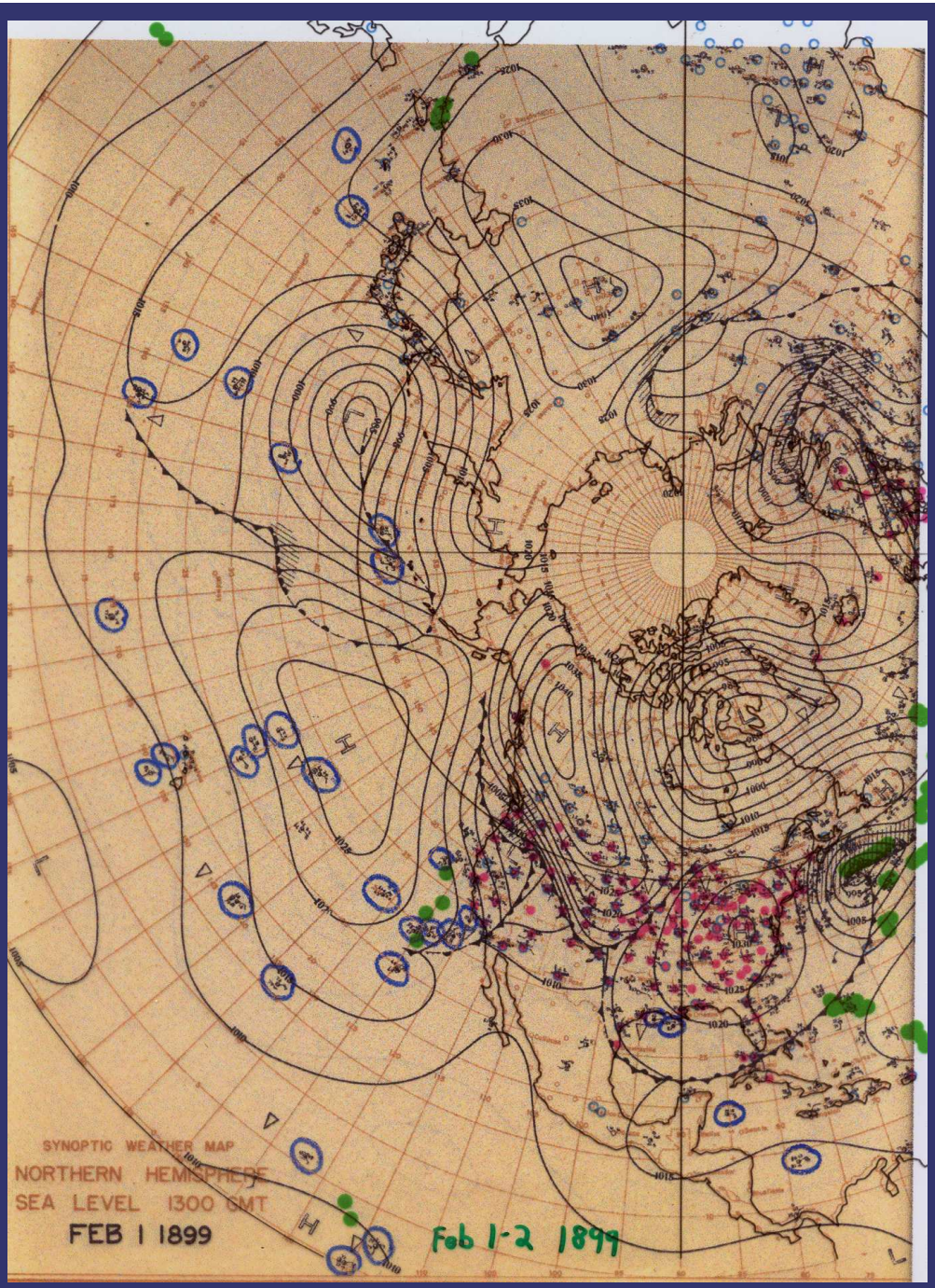
How many observations could be available?

Large open blue circles:

US Merchant Marine obs

Filled green circles:

ICOADS 2.0



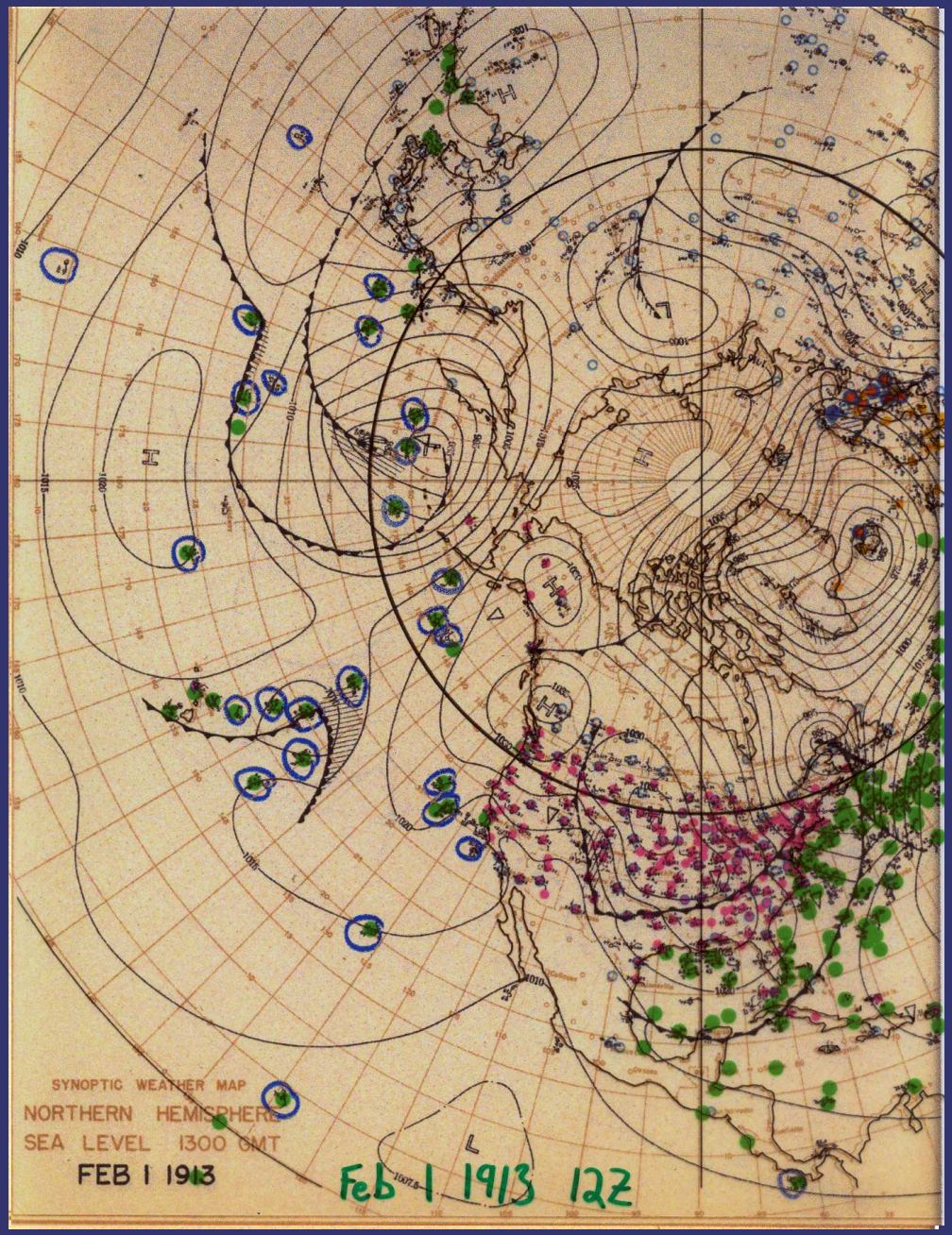
Comparison of ICOADS and US Historical Weather Map Feb 1 1913

Large open blue circles:

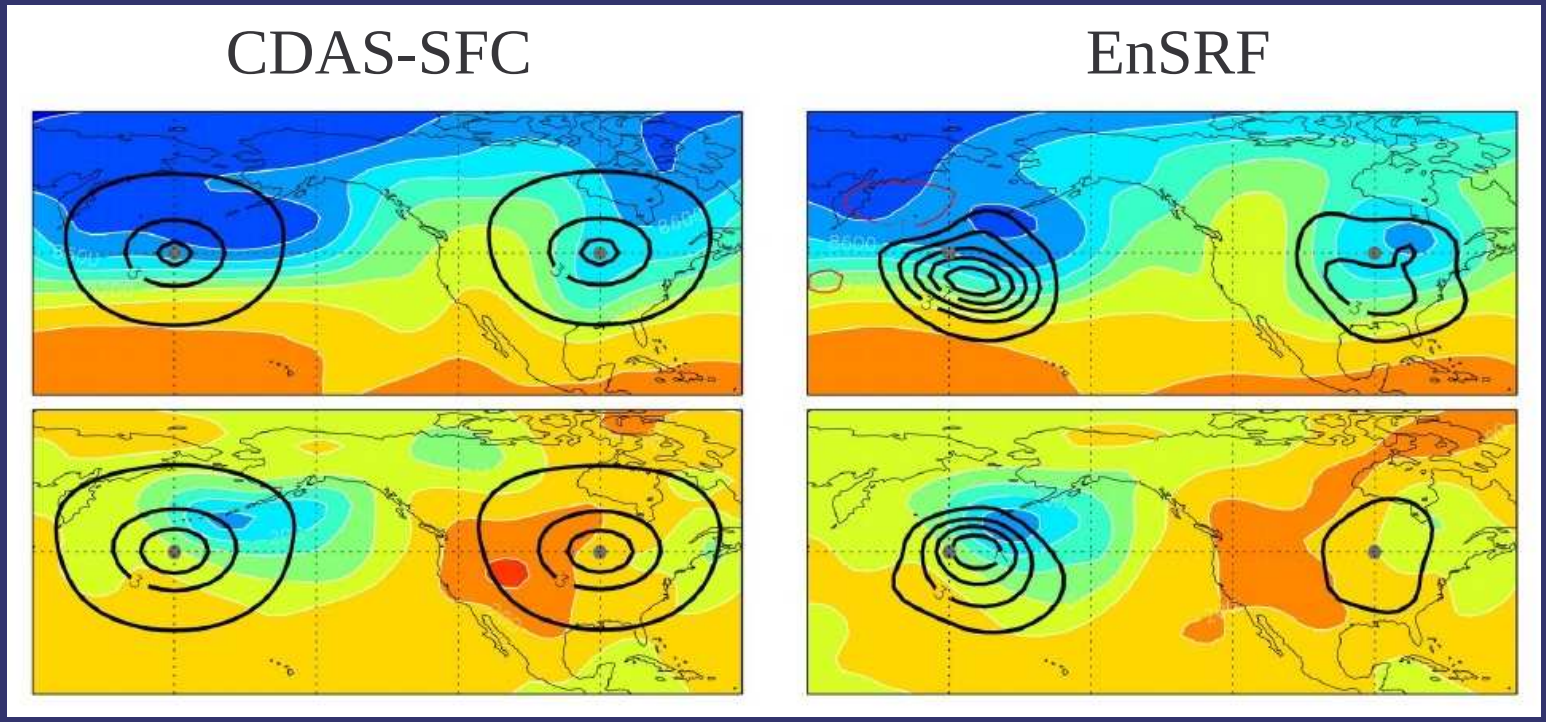
US Merchant Marine obs

Filled green circles:

ICOADS 2.0



Geopotential height first guess and analysis minus first guess for single pressure observations 1mb greater than first guess



Ensemble filter can extract spatially varying structures relative to the flow and the previous observational density.

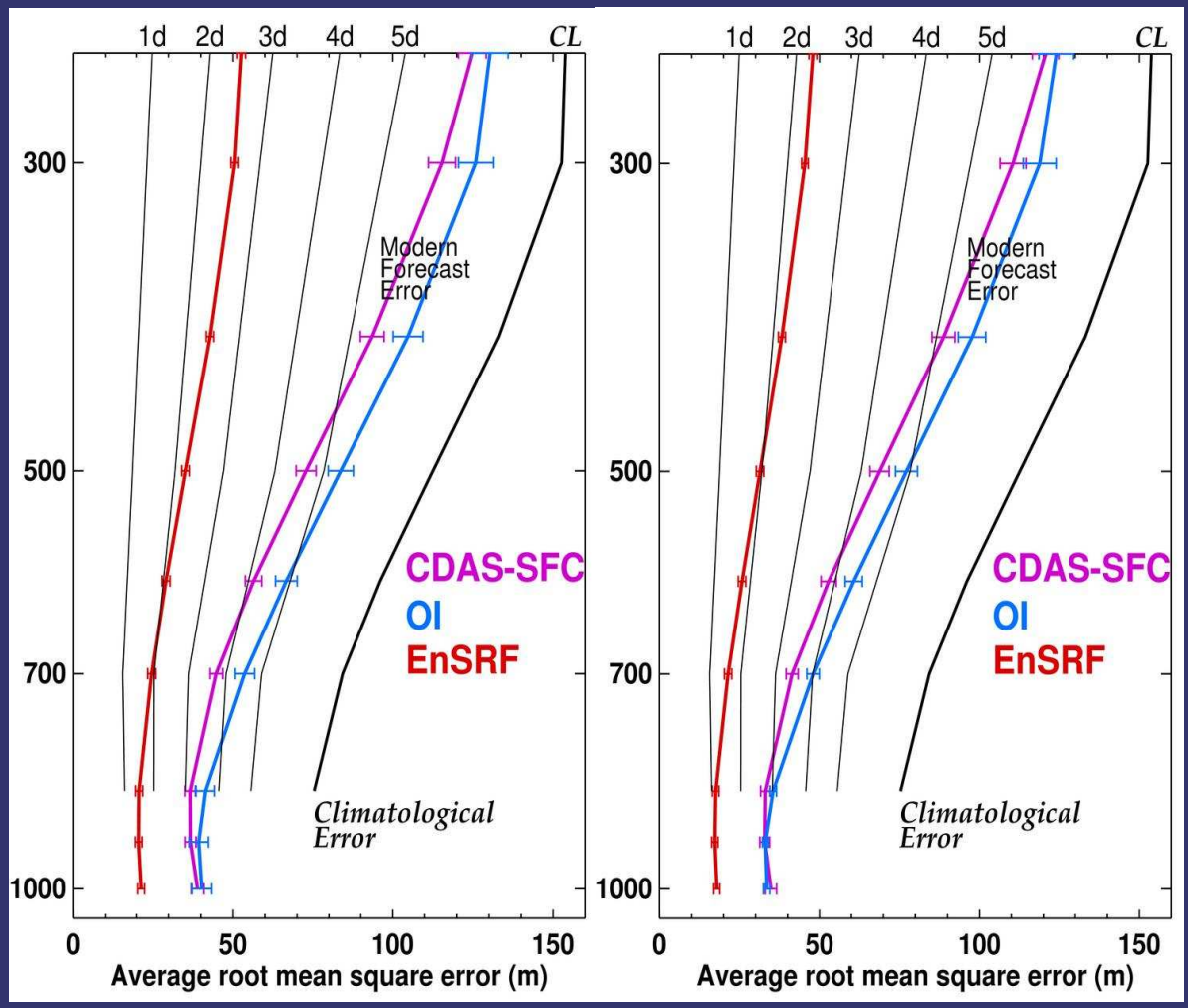
Root Mean Square Error of geopotential height analyses
CDAS-SFC, Optimal Interpolation, and Ensemble Square Root Filter
Using Only Surface Pressure Obs at 1915 Densities

6-hourly daily averages

OI {using ***climatology*** as first guess!} is competitive with CDAS-SFC for daily averages.

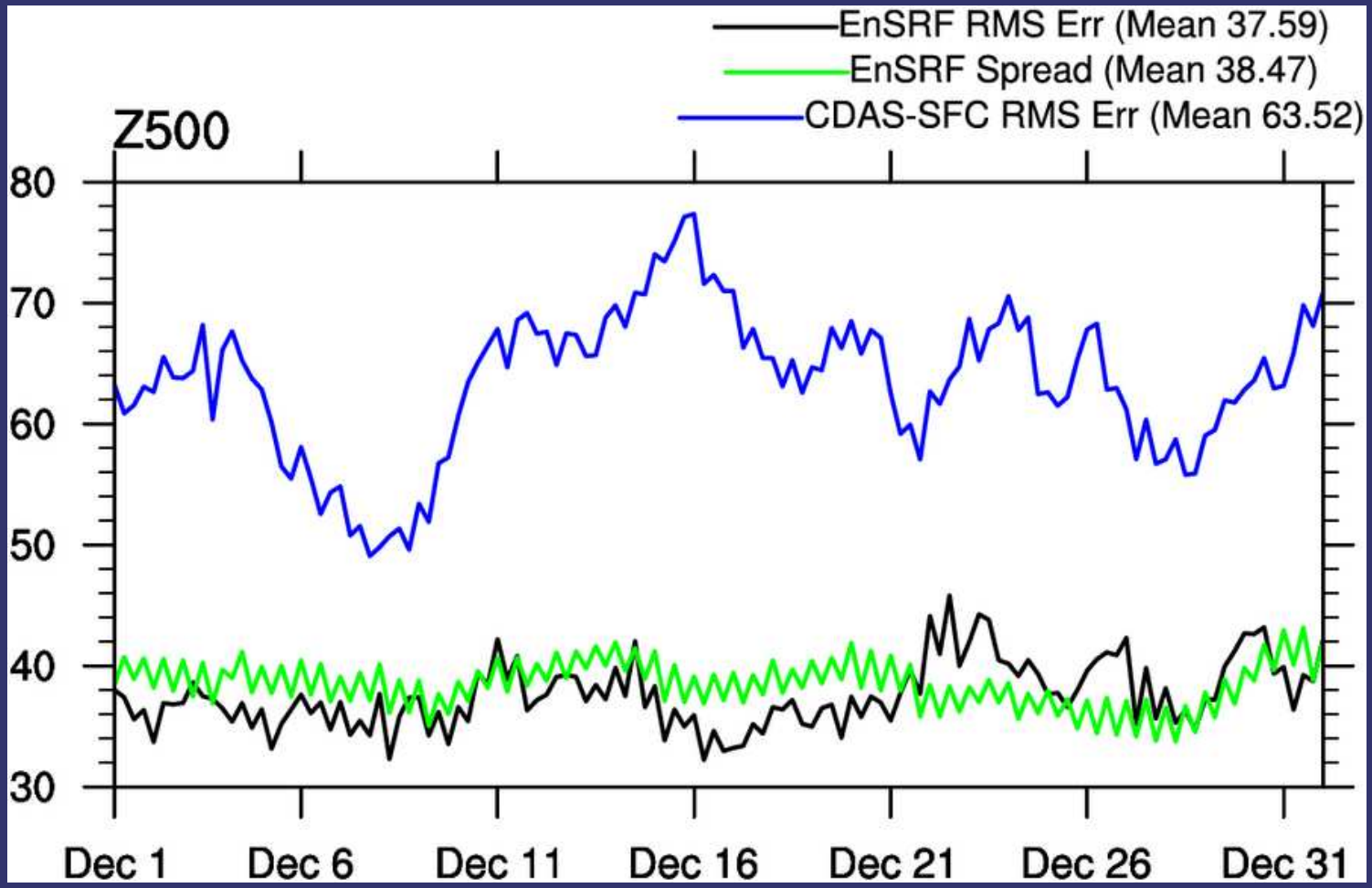
Results obtained using EnSRF remain better than the CDAS-SFC, but gap narrows with more obs.

Errors are comparable to 2-3 day forecast



Simulating December 2001

Root Mean Square Error of geopotential height analyses using CDAS-SFC and Ensemble Filter and Only Surface Pressure Obs at 1915 Densities



EnSRF error and spread are comparable and avoid large swings of the CDAS-SFC 3D-Var system.

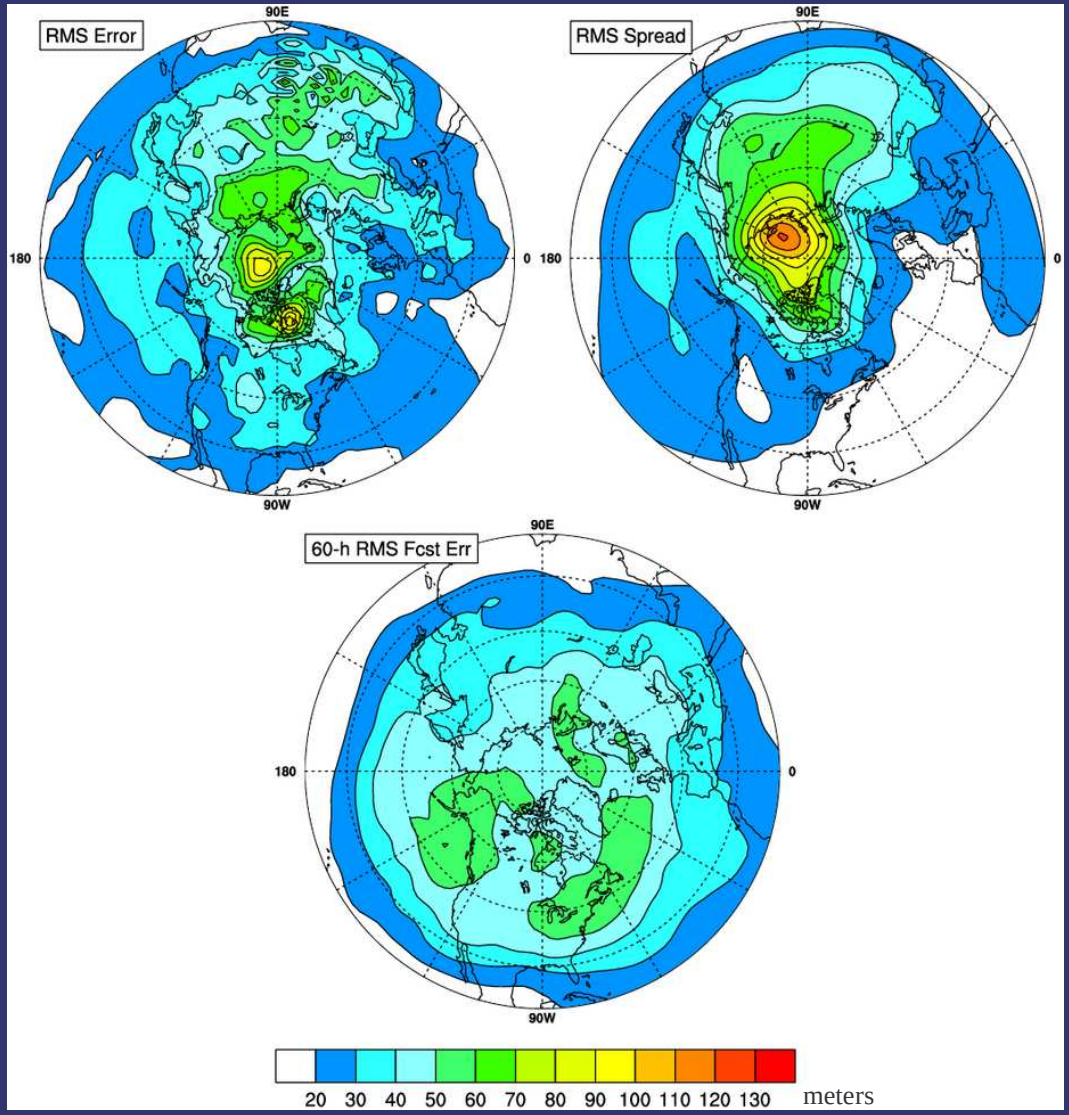
500 mb geopotential height statistics for Ensemble Filter using 1915 network compared to modern 60-hour forecast error

RMS Analysis Error

Covariance Inflation = 1.07

Covariance Local =5000 km

Differences between RMS error and Spread indicate simple tuned parameters not perfect.



Ensemble spread

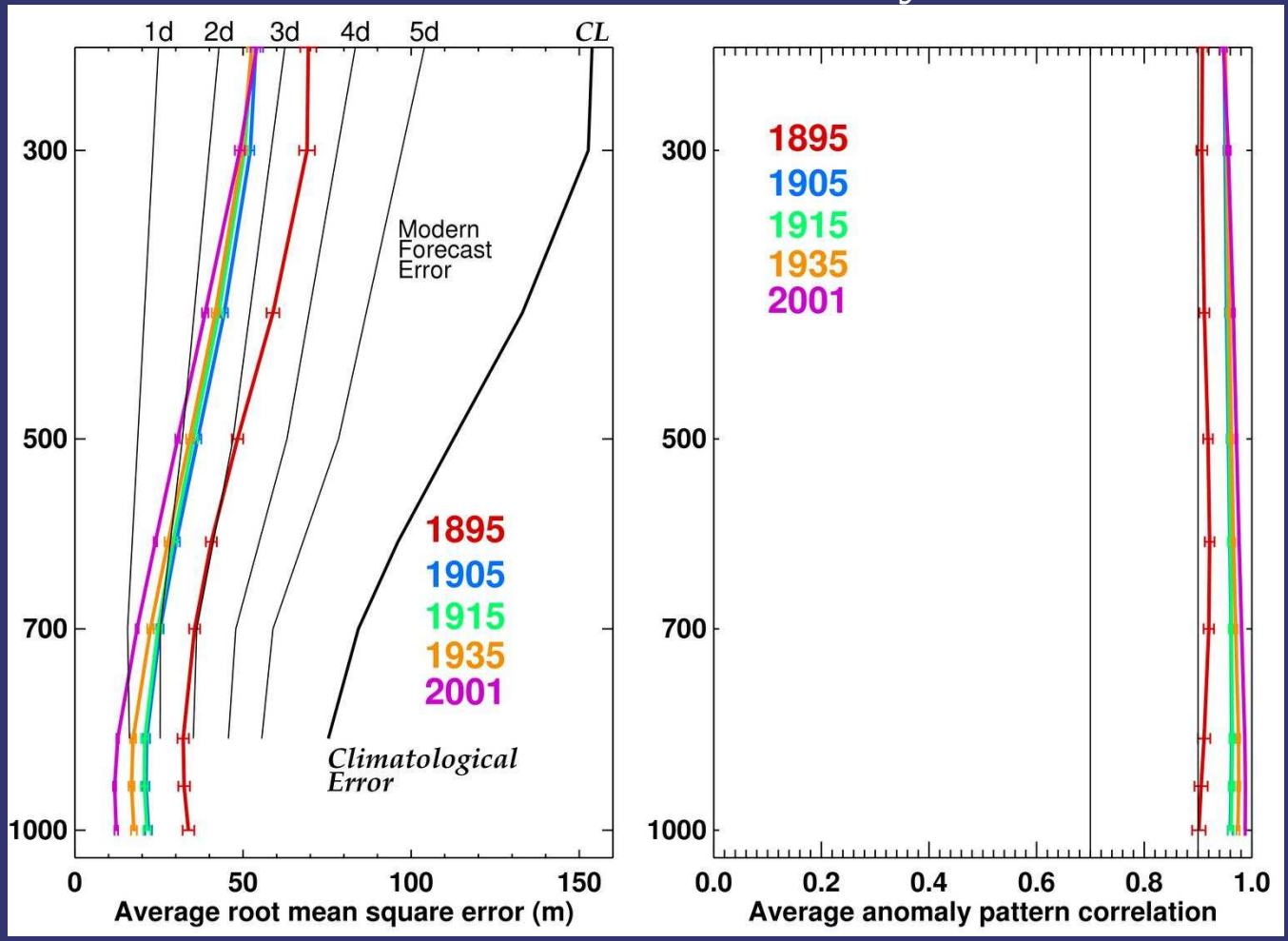
RMS 60-hr Forecast Error

RMS Error and Anomaly Correlation skill of
6-hourly geopotential height analyses using Ensemble Filter and
Only Surface Pressure Obs at 1895, 1905, 1915, 1935, and 2001 densities

RMS anomaly correlation

Increasing number and coverage of observations will help greatly for 1895 period.

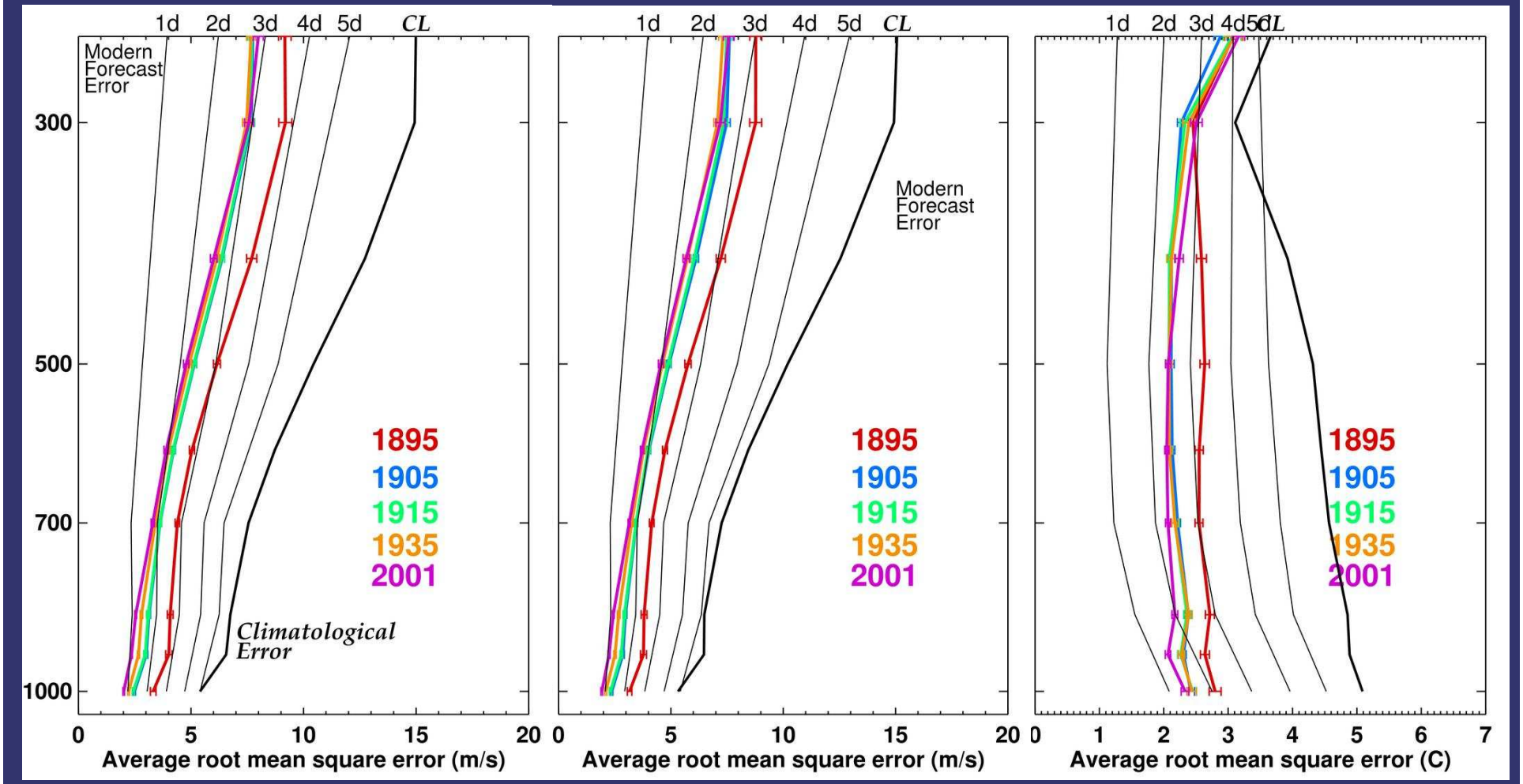
1905 only has 30 obs more per analysis, but much better coverage.



Simulating December 2001

Root Mean Square Error for Dec 2001
6-hourly winds and temperature analyses using Ensemble Filter and
Only Surface Pressure Obs at 1895, 1905, 1915, 1935, and 2001 densities

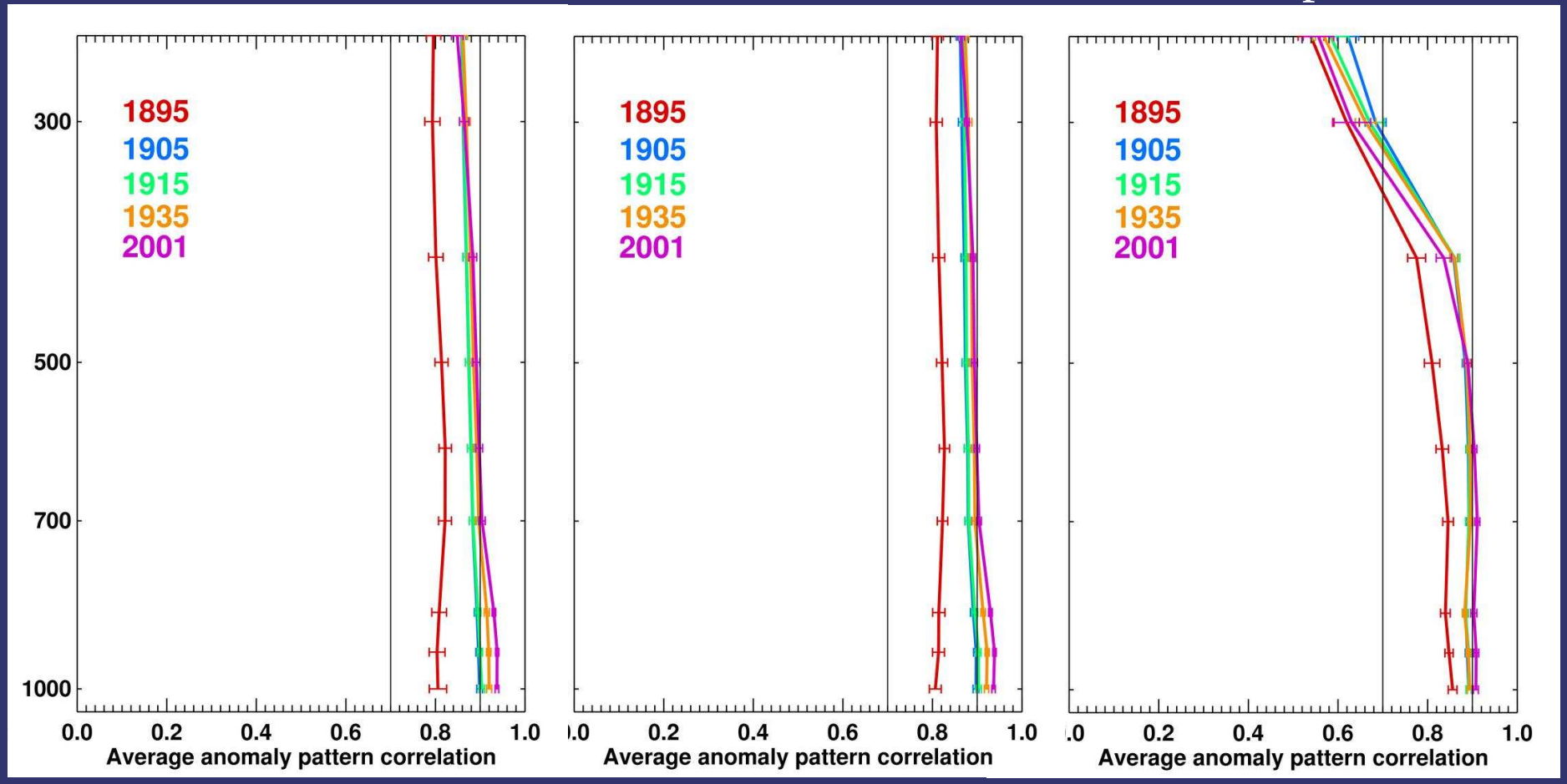
Zonal wind | Meridional wind | Air Temperature



Simulating December 2001

Anomaly Correlation Skill of analyzing Dec 2001
6-hourly winds and temperature using Ensemble Filter and
Only Surface Pressure Obs at 1895, 1905, 1915, and 1935 densities

Zonal wind | Meridional wind | Air Temperature



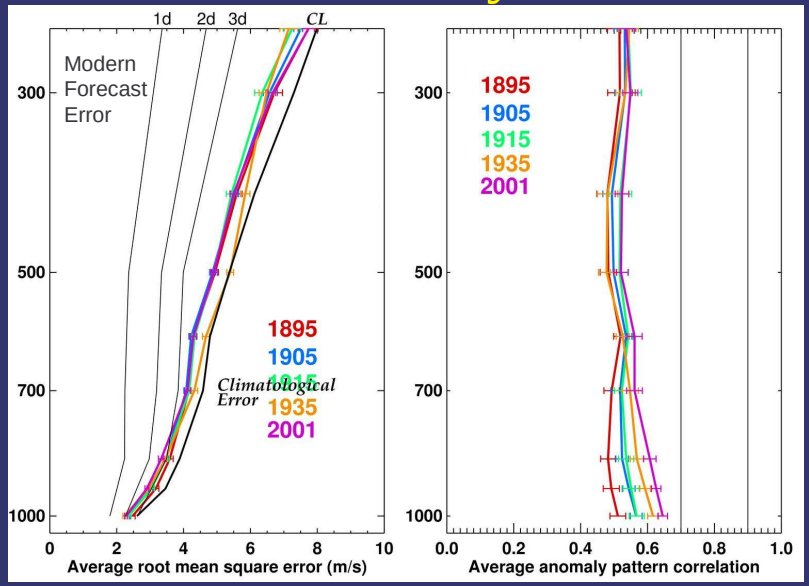
Skill of 6-hourly zonal wind "reanalyses" using Ensemble Filter and Only Surface Pressure Obs at 1895, 1905, 1915, 1935, and 2001 densities

RMS anomaly correlation

Analyses are poor in Tropics.

Tropics

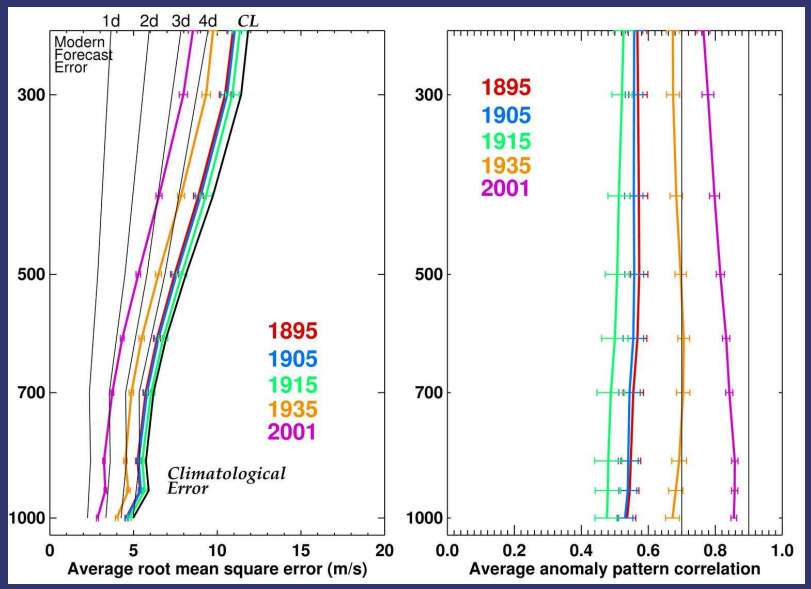
Southern Hemisphere may useful by 1930s.



Both regions have too few obs.

Model error in Tropics may also contribute.

Southern Hemisphere

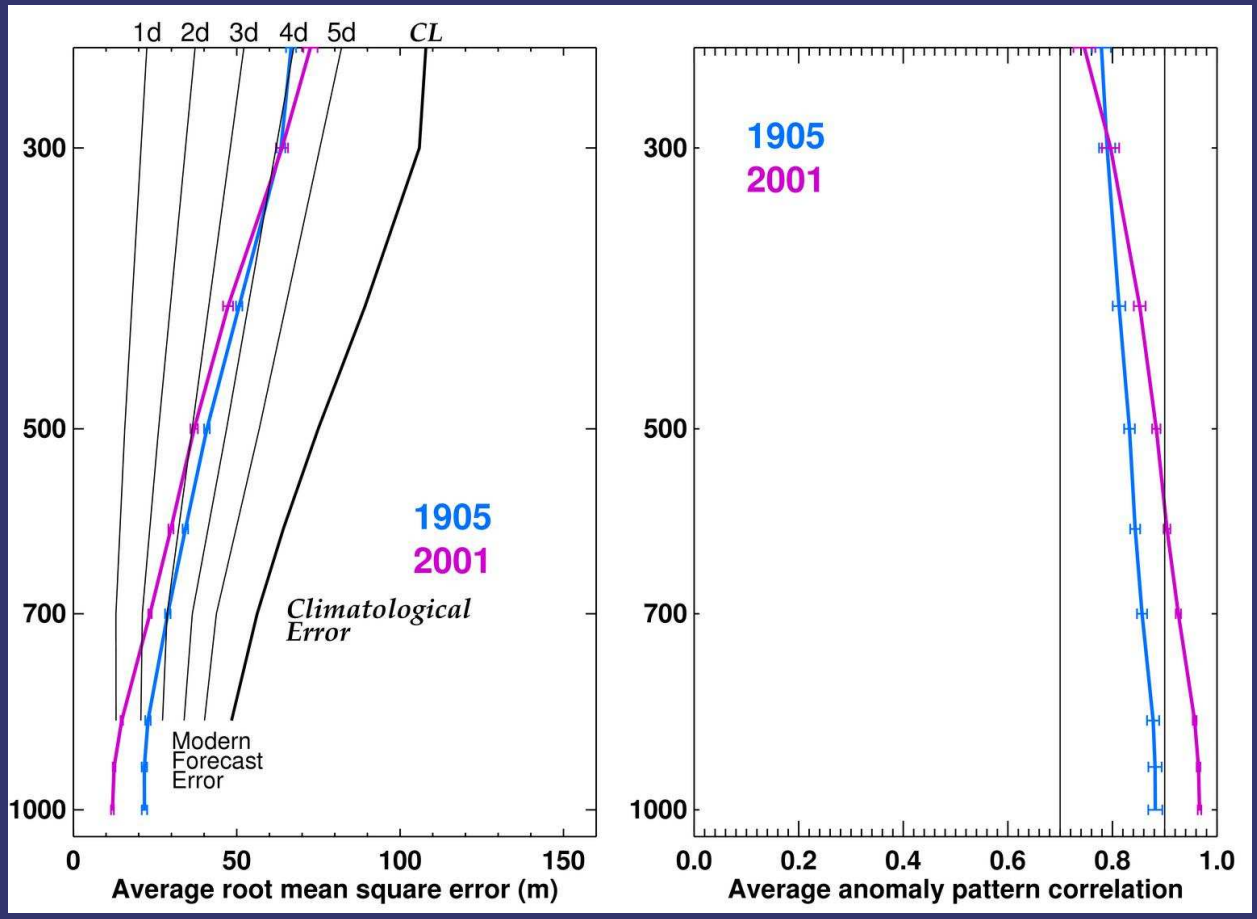


Simulating December 2001

RMS Error and Anomaly Correlation skill of 6-hourly geopotential height analyses for Northern Hemisphere June 2001 using Ensemble Filter and Only Surface Pressure Obs at 1905 and 2001 densities

RMS anomaly correlation

Increasing number and coverage of observations will help lower tropospheric analysis of early 20th century.

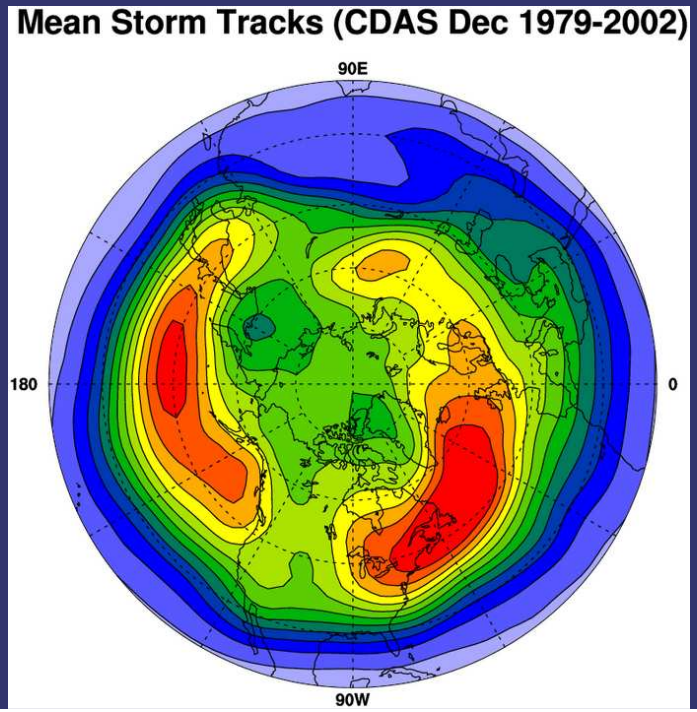


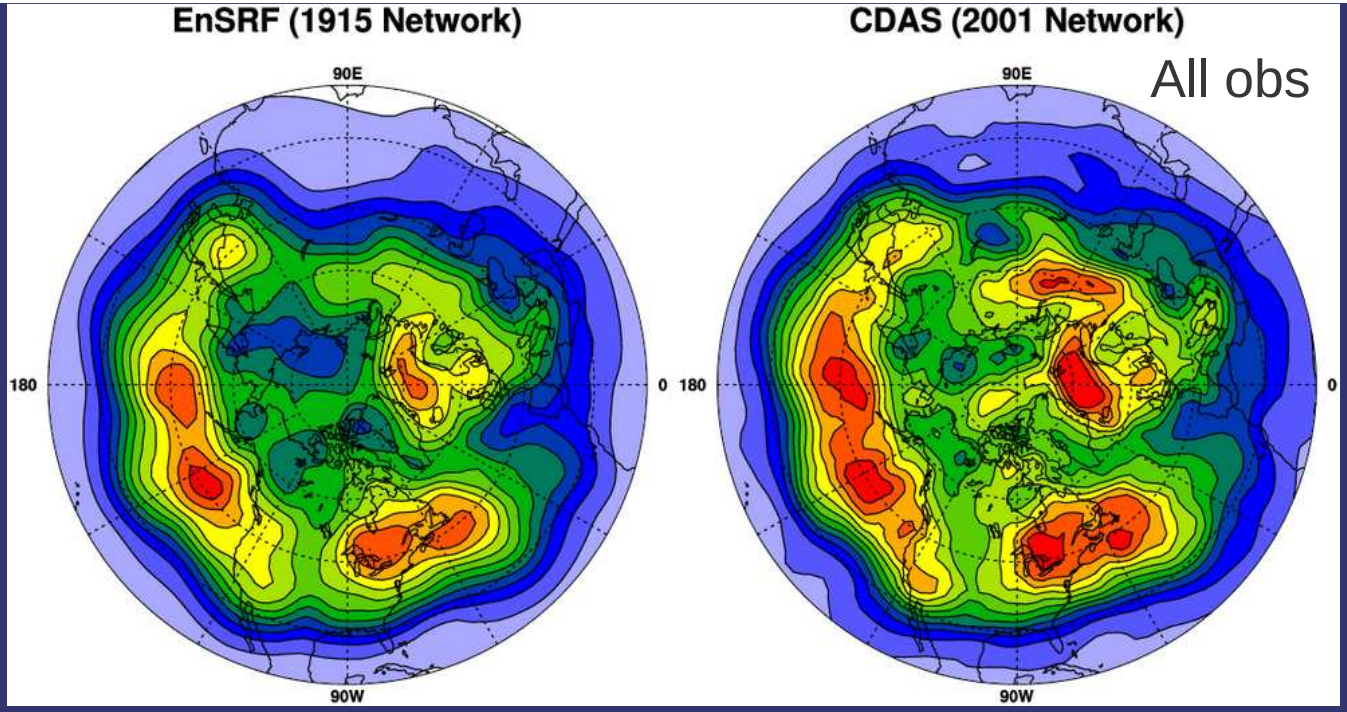
Storm track analysis

How well can we estimate monthly storm track variability with 1915 network?

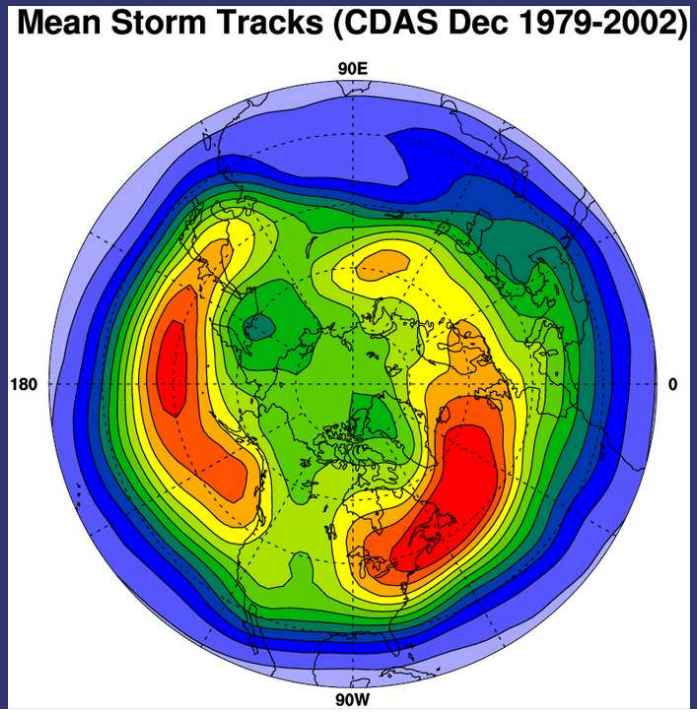
"Storm track" defined as standard deviation of 24-h 500 mb height tendency.

Mean of all Decembers 1979-2002 from CDAS shown below




EnSRF (1915 Network)
90E
180
0
90W

CDAS (2001 Network)
All obs
90E
180
0
90W


Mean Storm Tracks (CDAS Dec 1979-2002)
90E
180
0
90W

Conclusions

1. Reanalyzing the lower-tropospheric circulation of the entire 20th century is feasible in the Northern Hemisphere ***using just the available surface observations***.

2. Better methods than 3d-Var will produce better results, especially in the ***upper*** troposphere.

3. Keying additional marine observations, particularly US Merchant Marine pre-1913, will greatly increase the fidelity of the reanalysis and give errors comparable to current 2-3 day forecasts.